

Method of supplying a plasma torch with a gas, mixed gas or gas mixture and arrangement for supplying a plasma torch with a gas, mixed gas or gas mixture

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The present invention relates to a method of supplying a plasma torch with a gas, mixed gas or gas mixture, in which the volume flow of the gas, mixed gas or gas mixture is controlled. In addition, the present invention relates to an arrangement for supplying a plasma torch with a gas or mixed gas or gas mixture, with a means for delivering the gas or mixed gas or gas mixture to the plasma torch and a volume flow control means for controlling the volume flow of the gas or mixed gas or gas mixture.

Various gases are used as plasma gases, such as monatomic argon and/or the diatomic gases hydrogen, nitrogen, oxygen or air. These gases are ionised and dissociated by the energy of the plasma arc. A plasma mixed gas is a plasma gas which has already been premixed by the supplier, whereas a plasma gas mixture is a plasma gas that is only mixed on the spot.

As a rule, the plasma in a plasma torch is constricted by a water-cooled nozzle. In this way, energy densities of up to  $2 \times 10^6 \text{ W/cm}^2$  can be achieved. In the plasma arc of a plasma torch, temperatures of up to  $30,000^\circ \text{ C}$  arise, which, in combination with the high flow rate of the plasma gas, result in very high cutting speeds in all electrically conductive materials.

For a plasma cutting process, a pilot arc is first ignited between the nozzle and the cathode of the plasma torch by means of high voltage. This low-energy pilot arc prepares the path between the plasma cutting torch and the work piece by means of partial ionisation. When the pilot arc touches the work piece, the cutting arc forms.

Plasma cutting is an established method of cutting electrically conductive materials. Depending on the cutting task, various gases and gas mixtures are used. Conventional gases and gas

mixtures are, for example, air, oxygen, nitrogen and their gas mixtures, and also argon/hydrogen/nitrogen mixtures.

Unalloyed steels are cut with air or oxygen as a rule. Alloyed steels and non-ferrous metals are preferably cut with special argon/hydrogen, nitrogen/hydrogen or argon/hydrogen/nitrogen mixtures. In order to improve the quality of the cut, an additional secondary gas is also employed nowadays, which flows round the plasma jet in addition. The function of the additional secondary gas is to protect the nozzle of the plasma torch against material from the work piece splashing back when piercing the work piece and thus to protect it against damage; it also influences the molten metal during cutting in such a way that the cut produced is free of dross; and it acts as a shield gas to protect the surface of the cut, which is still hot after it has been cut, against oxidation.

These plasma and secondary gases, mixed gases and gas mixtures are delivered to the plasma cutting torches via lines and solenoid valves. The gases are usually metered by setting or adjusting the pressure.

The pressure may be controlled either mechanically via pressure reducers, or electronically via pressure control valves. The use of electronic pressure regulators is common, especially in automated systems, in which a wide range of plasma cutting parameters, such as the cutting current, the cutting voltage, the gas pressure, the cutting rate, the thickness of the material and the plasma cutting torch distance are stored in databases in order to achieve the greatest possible reproducibility of the cutting results.

DE 195 36 150 C2, for example, describes a means and method for gas control in a plasma torch, in which the gas flow is set by an arrangement consisting of a proportional valve, a pressure sensor and a shield in the plasma torch.

In EP 0 697 935 B1, the gas is metered by means of changeable needle valves. The cross-section of the needle valves, in combination with the pressure set, determines the amount of gas. The volume flow can be indicated in the process by means of variable-area flow meters.

Gas mixtures, which are needed in particular for processing alloyed steels and non-ferrous metals, cannot, however, be reproducibly generated by means of a pressure control. Attempts have therefore been made to reduce this disadvantage by using auxiliary devices. DD 54 347, for example, describes the use of a mixing chamber with pressure shields. This does not solve the problem either, however, since the mixing ratio is very restricted.

It is particularly difficult to mix gases of different densities and in widely varying mixing ratios. Even the use of various known mixing devices, such as T-fittings, injectors, labyrinth arrangements and arrangements of nozzles, as are described in DD 132247, for example, cannot produce the varying optimum mixing ratios required.

Gas metering by means of pure volume flow control is also known. This method can reproducibly create defined gas mixtures.

US 6,972,248 B1 discloses a method and arrangement for reducing electrode and nozzle wear in oxygen plasma cutting by using a mixture of oxygen and nitrogen instead of pure oxygen. In the known method, a constant volume flow of the individual plasma gases is produced by means of an arrangement consisting of needle valves and differential pressure gauges, such that the differential pressure upstream and downstream of the differential pressure gauges is kept constant by means of the needle valves upstream. Between the controlled member and the plasma torch there are pressure-reducing valves, which limit the maximum supply pressure to the plasma torch.

The German utility model DE 201 21 641.8 U1 describes a method in accordance with the preamble of claim 1 and an arrangement in accordance with the preamble of claim 14.

Even if a volume flow control is able, depending on the measuring method used, to generate a more or less constant volume flow of a gas or gases and reproducibly to produce a gas mixture, the quality of the cut in the cut materials, especially at the beginning of cutting, is inadequate. The inadequate quality of the cut may take the form of, for example, unreliable piercing (no or only a delayed transfer of a pilot arc, for example) of the material to be cut, unreliable cutting through (material left behind, for example), the formation of dross (slag on the underside of the work piece) and a major deviation in the angle (exceeding the tolerance of the right angle or slope, for example).

The invention is therefore based on the problem of improving the generic method and the generic arrangement in such a way that better cut qualities can be achieved with it.

This problem with the generic method is solved in accordance with the invention in that the volume flow control is effected in combination with a pressure control of the gas, mixed gas or gas mixture in such a way that the pressure control is used to adjust the level of the total volume flow through the nozzle of the plasma torch, and the volume flow control is used to adjust the volume flow portions producing the total volume flow, taking the desired gas composition into account.

In addition, this problem with the generic arrangement is solved in that the volume flow control means is combined with a pressure control means to control the pressure of the gas, mixed gas or gas mixture in such a way that the pressure control means is used to adjust the level of the total volume flow through the nozzle of the plasma torch, and the volume flow control means is used to adjust the volume flow portions producing the total volume flow, taking the desired gas composition into account.

In the method, it can be provided that the pressure in the interior of the plasma torch between the electrode and the nozzle of the plasma torch is measured directly or indirectly.

In particular, it can be provided that the pressure in the gas delivery means is measured upstream of the plasma torch.

According to a further particular embodiment of the invention, it can be provided that the volume flow control is effected by means of one or more volume flow control means, and the pressure is measured between the one or more volume flow control means and the plasma torch.

In addition, it is conceivable that the pressures of the individual gases or individual mixed gases are measured and a mean pressure is formed from the pressures measured.

Alternatively, the individual gases or individual mixed gases may be combined and the resulting pressure measured. The individual gases or mixed gases may be combined in that, for example, the gas hoses in which the individual gases or mixed gases are delivered are joined together. This creates a common space in which all three individual gases or mixed gases are present.

In addition, it can also be provided that at least two individual gases or mixed gases are combined and the resulting pressure is measured. This means that if the pressure is not measured for each individual gas or mixed gas, the amount of equipment needed can be reduced.

It is useful for the volume flow of a gas mixture to be controlled by controlling the volume flows of the individual gases or individual mixed gases of the gas mixture.

It is advantageous for at least one volume flow to be controlled on the basis of the calorimetric measurement of the volume flow, on the basis of the measurement of the volume flow from the differential pressure or on the basis of a pulse measurement.

According to a further particular embodiment of the invention, it can be provided that the plasma torch is additionally supplied with secondary gas or secondary mixed gas or a secondary gas mixture and the volume flow of the secondary gas or secondary mixed gas or secondary gas mixture is controlled.

In particular, it can in this case be provided that the volume flow control of the secondary gas, secondary mixed gas or secondary gas mixture is effected in combination with a pressure control of the secondary gas, secondary mixed gas or secondary gas mixture in such a way that the pressure control is used to adjust the level of the total volume flow of the secondary gas, secondary mixed gas or secondary gas mixture through the secondary gas nozzle of the plasma torch, and the volume flow control is used to adjust the volume flow portions producing the total volume flow, taking the desired secondary gas composition into account.

In an advantageous method, before being supplied with the gas, mixed gas or gas mixture, the plasma torch is supplied separately with a pre-flow gas at a controlled pressure, and/or after being supplied with the gas, mixed gas or gas mixture, it is supplied separately with a post-flow gas at a controlled pressure post-flow gas.

Finally, with this method, it can be provided that the gas, mixed gas or gas mixture is a plasma gas, plasma mixed gas or plasma gas mixture.

The dependent claims relate to advantageous embodiments of the arrangement of the invention.

The invention is based on the surprising finding that the volume flow actually passing through the nozzle of the plasma torch can be controlled by combining the volume flow control and pressure control in the claimed manner. As studies have shown, the quality of the cut is ultimately dependent on the volume flow actually passing through the nozzle of the plasma torch, and not on the gas volume flow flowing through the volume flow controllers. Gas hoses connecting the plasma torch to the volume flow controllers, however, mean that the volume flow through the volume flow controllers is not identical to the volume flow actually passing through the nozzle of the plasma torch. The difference between the volume flow in the volume flow controllers and the nozzle of the plasma torch can be explained by the volume of the gas hoses between them and the compressibility of gases.

This makes itself felt especially in transitions between the different operating conditions that occur during plasma cutting. In the interior of the plasma torch (between the electrode and the nozzle of the plasma torch) - depending on the operating condition, such as the start-up of the process, the pilot arc, the main arc and the end of the process -, different internal pressures are required in order to achieve a particular volume flow. These are generated by the changing arc currents, which produce different diameters of the plasma jet and in this way narrow the nozzle channel. The currents may be 10 – 25 A in the pilot arc, for example, and 20 – 1000 A in the main arc.

With the present invention, it is possible to react quickly to rapidly changing pressure conditions in the interior of the plasma torch, especially during the transition processes, such as igniting the pilot arc, transferring the pilot arc to the work piece and forming the main arc (cutting), without altering the mixing ratio of the gas mixture. This is done by superimposing the result of the pressure measurement on the set value of the volume flow control means in such a way that a pressure independent of the operating condition of the plasma torch is created in the space between the volume flow control means and the plasma torch, or in the interior of the plasma torch, and the mixing ratio of the gas mixture remains unchanged. This means that an ideal plasma gas mixture is available for the cutting process from the very beginning.

Both individual gases *per se* and the individual gases for gas mixtures can be controlled over wide ranges and thus adapted ideally to the cutting task at hand. In this way, a high level of reproducibility of the cutting results is achieved.

The volume flow can be set with the aid of proportional valves or motor-operated valves, for example. The pressure can be measured by means of pressure transmitters which are known *per se*.

The volume flow control and pressure control may be analogue or digital and may be actuated accordingly. The volume flow measured may be visualised and monitored.

The method of the invention can be integrated into a quality-control and documentation system. Evaluations together with other process parameters enable conclusions to be drawn with regard to the cutting quality.

Other features and benefits of the invention will become clear from the claims and the following description, in which two embodiments are explained in detail with reference to the schematic drawings. There,

Figure 1 shows schematically an arrangement for supplying a plasma torch in the form of a plasma cutting torch with a plasma gas mixture and a secondary gas mixture in accordance with a particular embodiment of the invention;

Figure 2 shows an arrangement for supplying a plasma torch in the form of a plasma cutting torch with a plasma gas mixture and a secondary gas mixture in accordance with a further particular embodiment of the invention;

Figure 3 shows schematically an arrangement for supplying a plasma torch in the form of a plasma cutting torch with a secondary gas mixture in accordance with a further particular embodiment of the invention; and

Figure 4 shows a detail from Figure 1.

Figure 1 shows an arrangement 10 for supplying a plasma torch in the form of a plasma cutting torch, of which only an electrode 12, a nozzle of the plasma torch 14 and a secondary gas nozzle 16 are shown, with an argon/hydrogen/nitrogen mixture for plasma cutting alloyed steels and non-ferrous metals. It comprises a means 18 for delivering a plasma gas mixture, which has a single gas source (not shown) for each individual gas, namely argon (Ar), hydrogen (H<sub>2</sub>) and nitrogen (N<sub>2</sub>), of the plasma gas mixture (argon/hydrogen/nitrogen mixture), which source is connected to a plasma gas mixing means 22 via a respective hose line 6a, 6b, 6c. The plasma gas mixing means is connected to the plasma torch nozzle 14 via a plasma gas mixture hose 9a.

In addition, a means 20 is provided for delivering a secondary gas mixture. This comprises sources (not shown) for the individual gases, which in this case are N<sub>2</sub> and H<sub>2</sub>, of the secondary gas, said sources being connected via respective hose lines 6d and 6e to a secondary gas mixing means 26, which is connected via a hose line 7d and a secondary gas mixture hose 9d to the secondary gas nozzle 16.

In each hose line 6a, 6b and 6c, and also 6d and 6e, there is in each case a pressure switch 2a, 2b, 2c, 2d and 2e, respectively, and a volume flow control means 1a, 1b, 1c, 1d and 1e, respectively, and a solenoid valve 3a, 3b, 3c, 3d and 3e, respectively, arranged in series.

Furthermore, there is a pressure measuring means 4a, 4b and 4c, respectively, in the means 18 for delivering a plasma gas mixture, downstream of the respective solenoid valve 3a, 3b and 3c, respectively. The pressure measuring means 4a, 4b and 4c are connected via signal lines to a

control means 5, which in turn is connected to the volume flow control means 1a, 1b and 1c via a respective control line.

Downstream of the pressure measuring means 4a, 4b and 4c, respective solenoid valves 8a, 8b and 8c are provided in the hose lines 7a, 7b and 7c. Downstream of the solenoid valves 8a, 8b and 8c, the hose lines 7a, 7b and 7c are combined into the plasma gas mixture hose 9a.

In the means 20 for delivering a secondary gas mixture, the hose lines 6d and 6e are combined via the secondary gas mixing means 26 into the hose line 7d downstream of the solenoid valves 3d and 3e. Downstream of that, a solenoid valve 8d is provided on the side of the plasma torch.

The operation of the arrangement 10 of Figure 1 will now be explained:

The individual gases for the plasma gas, in the present case argon, nitrogen and hydrogen, are delivered to the volume flow control means 1a, 1b and 1c via the hose lines 6a, 6b and 6c. The pressure switches 2a, 2b and 2c monitor the presence of a minimum required gas pressure. Individual set values for the volume flow  $w_1$ ,  $w_2$ ,  $w_3$  are transmitted by the control means 5 according to the selected parameters for the respective volume flow control means 1a, 1b and 1c. Before the plasma cutting process begins, the solenoid valves 3a, 3b and 3c and initially also the solenoid valves 8a, 8b and 8c are opened in order to purge the hose lines 6a, 6b and 6c. After that, the hose lines 6a, 6b and 6c are filled, via the volume flow control means 1a, 1b and 1c, to the pressure determined by the control means 5, which is detected by the pressure measuring means 4a, 4b and 4c. This is done with the solenoid valves 8a, 8b and 8c closed, so that the pressure can build up. It is advantageous for the hose lines 6a, 6b and 6c to be filled to the same pressure, e.g. 4 bar, so that, at the beginning of the plasma cutting process, no equalisation processes between the individual gases occur.

At the beginning of the plasma cutting process, the solenoid valves 3a, 3b, 3c and 8a, 8b and 8c are opened, and the corresponding volume flows of the individual gases and thus the total volume flow of the plasma gas mixture are set. In the process, the pressure measured by a pressure measuring means, e.g. 4a, is evaluated by the control 5, since, when the solenoid valves 8a, 8b and 8c are open, a space has formed in which all the hose lines 6a, 6b and 6c are connected together. It is also possible to evaluate all the pressure measuring means 4a, 4b and 4c and then, for example, to calculate a mean pressure on the basis of the pressures measured. In the pre-flow period, i.e. immediately before the pilot arc is ignited, a defined plasma gas mixture then flows through the plasma torch at a preselected pressure, e.g. 4 bar. The resulting pressure is transmitted to the control means 5 and processed in such a way that the selected set values for the volume flow  $w_1$ ,  $w_2$  and  $w_3$  are converted into new set values for the volume flow  $w_1^*$ ,  $w_2^*$  and  $w_3^*$ , which set the desired pressure in the interior of the plasma torch at a constant gas mixture between the volume flow control means 1a, 1b and 1c and the plasma torch. After the ignition of the pilot arc, the pressure is increased to the pressure required for the plasma cutting process, e.g. 6 bar. This is done by raising the pressure set value  $p_{\text{sol}}$  (see Figure 4) in the control means 5, whereby the increased pressure set value  $p_{\text{sol}}$  raises the volume flows of the individual gases accordingly. This ensures that the desired pressure is always present in the interior of the plasma torch and the desired plasma gas mixing ratio is always given.

Even pressure fluctuations upstream of the plasma torch during the operating conditions are compensated for, e.g. when the current is reduced when cutting a corner or at the end of a cut.

The volume flows of the individual gases, and thus the mixing ratio, are selected with the set values for the volume flow  $w_1$ ,  $w_2$  and  $w_3$ . The pressure upstream of the plasma torch determines the pressure in the interior of the plasma torch between the electrode 12 and the nozzle of the plasma torch 14 and thus also the volume flow which ultimately flows through the nozzle of the plasma torch 14. The pressure achieved by the set volume flows is measured by means of the pressure means 4a as the pressure actual value  $p_{\text{ist}}$  and transmitted to the control means 5. If this pressure actual value  $p_{\text{ist}}$  is not identical to the selected pressure set value  $p_{\text{sol}}$ , in other words if

the volume flows through the volume flow control means 1a, 1b and 1c are not sufficient to achieve the pressure set value  $p_{\text{sol}}$ , the pressure difference  $\Delta p = p_{\text{sol}} - p_{\text{ist}}$  is calculated and, multiplied by a factor  $k$ , added to the set value for the volume flow  $w_1$ ,  $w_2$  or  $w_3$ , respectively, of the volume flow control means 1a, 1b and 1c. This is shown by the following equation:

$$w^* = w + k \times \Delta p.$$

This results in the processed set values for the volume flows  $w_1^*$ ,  $w_2^*$  and  $w_3^*$ . If the pressure actual value  $p_{\text{ist}}$  is greater than the pressure set value  $p_{\text{sol}}$ ,  $\Delta p$  is negative (see Figure 4). As a result, the set values for the volume flow for the volume flow control means 1a, 1b and 1c are reduced. The volume flows, gas mixtures and pressures that can be set can be limited by software to meaningful and safe values on a control panel.

It goes without saying that, with the arrangement described above, it is also possible to regulate individual gases, oxidising ones, such as air and oxygen, and non-oxidising ones, such as argon, hydrogen, nitrogen or mixtures thereof.

It is also possible to cut unalloyed steel with the plasma torch using air and oxygen and to cut alloyed steels using an argon/hydrogen/nitrogen mixture.

In addition, it is possible to perform a plasma cutting and plasma marking process with this arrangement. When swapping between the above-mentioned processes, it is necessary to switch over between different plasma gases. In plasma cutting structural steel, for example, oxygen is used, while an argon/nitrogen mixture is used in plasma marking. The change in plasma gas in this case should take place as quickly as possible, in order to maintain high productivity. It must, however, be ensured that the plasma gas has been replaced completely. For this reason, the hose lines 6a, 6b and 6c must be vented and purged and filled with the new plasma gas mixture. Since

the nozzle of the plasma torch 14 often has a very small bore (with a diameter of 0.7 mm, for example), this process can take a relatively long time, depending on the length of the hose lines, such as 10 seconds or longer. In order to reduce this time, a solenoid valve 8e is provided which rapidly vents the gas hoses 7a, 7b and 7c when the solenoid valves 8a, 8b or 8c are open. In this way, the time can be reduced to less than 3 seconds.

Figure 2 shows an arrangement 10, which differs from the arrangement of Figure 1 in that it possesses a combined pre-flow and post-flow gas delivery means, comprising a solenoid valve 3f, a hose line 7f and a solenoid valve 8f, for delivering a pre-flow and post-flow gas to the plasma torch separately, and in that it has a pressure control means 17 for controlling the pressure of the pre-flow and post-flow gas. In addition, the arrangement 10 of Figure 2 differs from the arrangement of Figure 1 in that the plasma gases argon and nitrogen are already mixed in a plasma gas mixing means 24 in the means 18 for delivering a plasma gas mixture.

The advantage of the arrangement 10 of Figure 2 consists in the fact that the pre-flow gas can flow through the plasma torch at a different pressure, e.g. 4 bar, while the gases needed for plasma cutting are already present as far as the solenoid valves 8a and 8c at the pressure required for plasma cutting, e.g. 6 bar, before the plasma cutting begins. This dispenses with the need, which still existed in Figure 1, to switch over the pressure from 4 bar to 6 bar when the pilot arc is ignited. During the pre-flow, the solenoid valves 3a, 3b, 3c and 3f and the solenoid valve 8f are open. The hose lines 7a and 7c are filled by the volume flow control means 1a and 1c up to the pressure laid down by the control means 5, which is detected by the pressure measuring means 4a and 4c. At this stage, the solenoid valves 8a and 8c of the plasma torch are closed so that the pressure of 6 bar, for example, can build up.

After the pilot arc is ignited, the solenoid valves 8a and 8c are opened and the solenoid valves 3f and 8f are closed. Here too, the measured pressure values from the pressure measuring means 4a are processed in the control means 5 to influence the volume flows of the individual gases in such a way that the desired pressure and the desired plasma gas mixing ratio are always available

at the plasma torch. After the plasma cutting has finished, the solenoid valves 8a and 8c are closed again and the solenoid valves 3f and 8f are opened. In this way, post-flow gas can then be delivered.

In Figures 1 and 2, the secondary gas is controlled only by the volume flow control means 1d and 1e, which keep the secondary gas volume flow constant throughout the entire plasma cutting process while the solenoid valves 3d, 3e and 8d are open. In the case of plasma torches which are constructed such that the bore of the secondary gas nozzle 16 is not significantly narrowed by a plasma jet, this is sufficient. This applies to plasma torches in which the bore of the secondary gas nozzle 16 is at least twice as large as the nozzle of the plasma torch 14. When the diameter ratios are smaller, the same method needs to be applied for supplying secondary gas as for supplying plasma gas. This is illustrated in Figure 3. This therefore requires a combined volume flow and pressure control of the secondary gas by analogy with the volume flow and pressure control employed in supplying plasma gas in accordance with Figures 1 and 2.

The method of supplying with gas is in principle also suitable for plasma technologies, such as plasma welding, plasma gouging and plasma marking.

In the embodiments described, the pressure in the interior of the plasma torch has been measured indirectly via the pressure measuring means 4a, 4b and 4c. It goes without saying that, alternatively, a pressure measuring means may be provided for measuring the pressure in the interior of the plasma torch directly.

The features of the invention disclosed in the present description, in the drawings and in the claims can be essential to implementing the invention in its various embodiments both individually and in any combination.

### List of reference numerals

1a, 1b, 1c, 1d, 1e	Volume flow control means
2a, 2b, 2c, 2d, 2e	Pressure switch
3a, 3b, 3c, 3d, 3e, 3f	Solenoid valves
4a, 4b, 4c	Pressure measuring means
5	Control means
6a, 6b, 6c, 6d, 6e	Hose lines
7a, 7b, 7c	Hose lines
7f	Hose line
8a, 8b, 8c	Solenoid valves
8d, 8f	Solenoid valve
9a	Plasma gas mixture hose
9d	Secondary gas mixture hose
10	Arrangement
12	Electrode
14	Nozzle of the plasma torch
16	Secondary gas nozzle
17	Pressure control means
18	Means for delivering a plasma gas mixture
20	Means for delivering a secondary gas mixture
22	Plasma gas mixing means

24	Plasma gas mixing means
26	Secondary gas mixing means
k	Factor
w1, w2, w3	New set values for the volume flow
w1 <sup>*</sup> , w2 <sup>*</sup> , w3 <sup>*</sup>	Set values for the volume flow
p <sub>soll</sub>	Pressure set value
p <sub>ist</sub>	Pressure actual value